ASPECTS OF THE ECOLOGY AND BREEDING BIOLOGY OF *GALAXIAS FUSCUS* MACK, IN THE GOULBURN RIVER SYSTEM, VICTORIA

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The ecology of *Galaxias fuscus* Mack (1936), an endangered galaxiid which is listed on the Victorian Flora and Fauna Guarantee Act, was studied in the upper Taggerty River. Several differences in the ecology of *G. fuscus* and *Galaxias olidus* Gunther were found, further supporting claims for *G. fuscus* to be recognised as a taxon independent of *G. olidus*. *Galaxias fuscus* was found to have a spawning season from August until September, *G. olidus* in comparison began to spawn two weeks earlier and was completed in mid-September, earlier than that of *G. fuscus*. The size distribution of *G. fuscus* has a higher proportion of larger fish, than that of *G. olidus*, with *G. fuscus* being on average a larger fish. The microhabitat of *G. fuscus* was found to be slow (<0.20 ms^{-1}) deep (mean depth 434 mm) pools, adjacent to faster flowing sections of stream.

GALAXIIDS are a Southern Hemisphere salmoniform fish, which are found in a wide range of habitats throughout southern Australia (McDowall 1980). One of the more widespread species of galaxiids in Australia is the mountain galaxiid, *Galaxias olidus*, which inhabits fast flowing mountain streams through the eastern coastal region of Australia, from Queensland to South Australia (Cadwallader & Backhouse 1983). The ecology of *G. olidus* has been well studied by various authors (Cadwallader et al. 1980; Cowden 1988; Drayson 1989; Fletcher 1979; Harasymiw 1970; O'Connor & Koehn 1991) with considerable attention being focused on the taxonomy of this species (Frankenberg 1966; McDowall & Frankenberg 1981; Rich 1986; Terzis 1986). There are many morphological variants of *G. olidus*, with McDowall & Frankenberg (1981) recognising 10 of these. They stated that *G. olidus* was a phenotypically plastic species and consequently synonymised 10 species under *G. olidus*. *Galaxias fuscus* Mack is the most morphologically distinct variant of *G. olidus* (McDowall & Frankenberg 1981), and can be distinguished by its base colour and superficially dark surface bars in varying numbers on the sides of the fish. There continues to be uncertainty concerning the species status of *G. fuscus*, with Allen (1989) recently considering it as a distinct species. Originally described from the Rubicon River in 1936 (Mack 1936a, 1936b), only a few specimens of *G. fuscus* have since been collected in Victoria from few sites.

G. fuscus is recognised as an endangered taxon Australia wide (Jackson 1991; ANZECC 1996) and is currently listed on the Victorian Flora and Fauna Guarantee Act 1989 as being a rare and endangered taxon (SAC 1991). The only completed studies to date concerning *G. fuscus* have been intermittent distributional surveys by the Victorian Department of Natural Resources and Environment and a limited electrophoretic study with inconclusive results (Rich 1986). A research recovery plan has been developed by the Victorian Department of Natural Resources and Environment to guide management of *G. fuscus* (Raadik 1995).

Previously, no work had been conducted on the ecology of this taxon and the assumption has been that the ecology of *G. fuscus* was identical to the other variants in the *G. olidus* species complex. In this paper we present the results of a study on aspects of the ecology of *G. fuscus*, including spawning ecology, habitat preference and population size and structure, and compare these with the known ecology of *G. olidus*.

STUDY SITES

The restricted range of *G. fuscus*, which is found only in the upper reaches of the Goulburn River system in Victoria, limited the number of sites available for study. The Taggerty River system, a tributary of the Goulburn River in the southern highlands of Victoria, approximately 90 km north east of Melbourne, was selected as the primary region of study (Fig. 1). The river rises on the slopes of Lake Mountain and the upper reaches of the drainage are included in the Lake Mountain Alpine Reserve. The geography of the Lake Mountain region is described by Morris (1929). In its lower reaches, the river flows through State forest until its confluence with the Steavenson River near the town of Marysville. The study of the ecology of *G. fuscus* was undertaken between the months of April and October 1991, at seven sites on the Taggerty River and Keppel Hut Creek a tributary of the Taggerty River.

A study of the ecology of *G. olidus* was undertaken concurrently, to allow comparisons to be made between the two taxa, by monthly sampling of a population at one site on Little River also in the Marysville area. This site is at a similar altitude (900–1100 m), but about 7 km NNE of the *G. fuscus* sites (Fig. 1).

METHODS

Due to the endangered species status of the taxon, all data were obtained by non-destructive sampling methods. Electrofishing was the preferred method of collection of fish, although bait traps, seine nets and dip nets were used where access was difficult. Stop nets, with a mesh size of 1 mm, were set downstream of the sampling area when electrofishing during high stream flows.

Sampling of populations of *G. fuscus* was undertaken at two sites in Keppel Hut Creek (KHC3 and KHC5) (37°28′S,145°50′E) and four sites in the Taggerty River (TAG1–TAG4) (37°29′S, 145°51′E) fortnightly to monitor reproductive development and determine the time of spawning. Rotation of sites sampled was undertaken to minimise potential disturbance of fish and their habitat by reducing the frequency of electrofishing in specific regions. *G. olidus* was also sampled monthly in Little River (Site LR1) to monitor reproductive development.

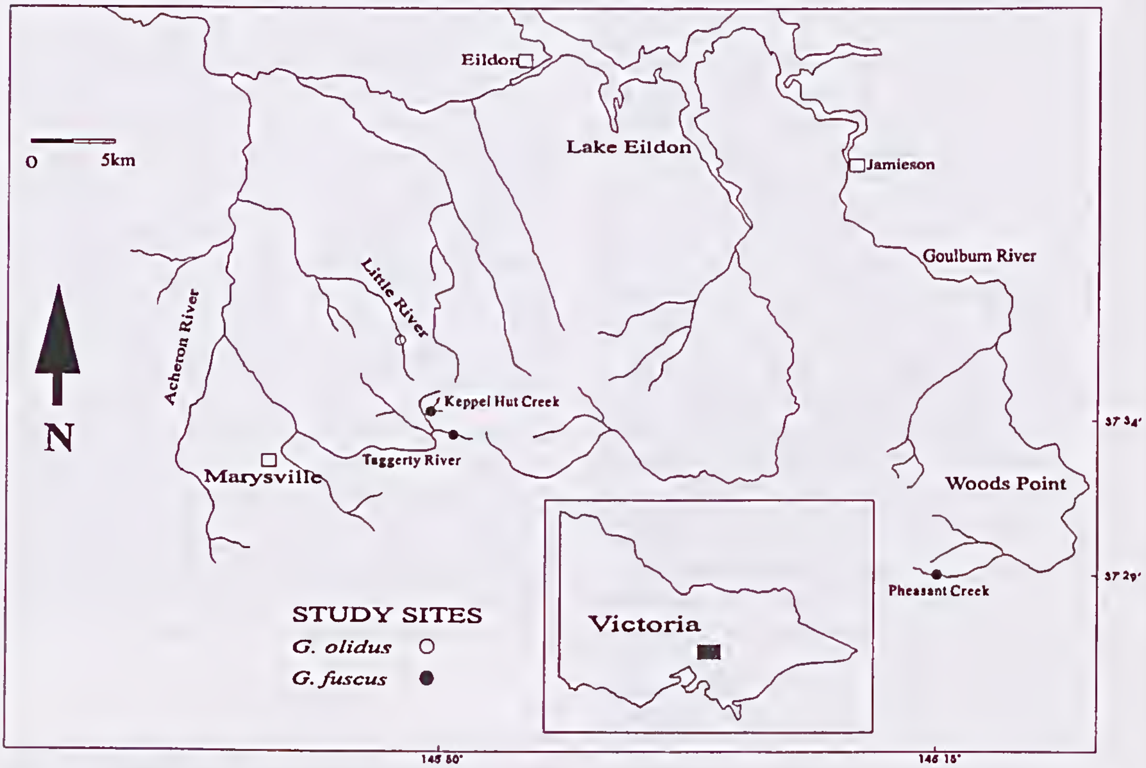


Fig. 1. The location of the study sites in the upper Goulburn River.

Prior to the collection of each fish sample water temperature and conductivity was measured mid flow.

All fish caught were measured as length to caudal fork (L.C.F.), and the microhabitat details of individual fish were recorded. Habitat use of *G. fuscus* was determined from microhabitat measurements at the point of capture of each individual. Variables which were measured included; mean water velocity (using a Tsurumi–Seiki Flow Meter suspended in the water at two-thirds of the water depth, for two minutes), type of substrate recorded on a descriptive scale [leaf litter, sand, silt, pebbles (<5 mm diameter), cobbles (5–20 mm diameter), rocks (>20 mm diameter)] and mean water depth. The mean water depth was calculated by measuring depths in the microhabitat area on a 1000 mm^2 square grid at 100 mm intervals. Reproductive state, sex and the number and pattern of full and partial bars on the sides of the fish was recorded for each specimen collected. All fish were then returned to the point of collection.

The states of reproductive development used by other authors (Pollard 1972; Humphries 1986) have been designed for studies involving dissection, consequently we used modified states more applicable for describing gonads visible through the body wall of live fish. They were: fully developed when gonads were visible through the body wall, running ripe being when eggs or milt were discharged with gentle pressure to the abdomen, spent when no gonadal material was visible after spawning and not ripe any other state.

Fecundity data was obtained from preserved museum specimens of 14 *G. fuscus* individuals (N.M.V. A8126, A84848, A7945, A7854, A7858, A7935: Arthur Rylah Institute for Environmental Research Collection, Department of Conservation and Natural Resources, 1987–92).

The endangered status of *G. fuscus* precluded the use of tag recapture studies or the removal method (Zippin 1958) to accurately determine population size. In order to limit stress and damage to the fish they were retained in buckets for the minimum time necessary and returned to the water as soon as possible. A determination of the population structure and an estimate of the population size of *G. fuscus* was obtained by counting the fish captured and excluding those recognised, by their size and the pattern of their bars, as having been recaptured.

After spawning had begun, egg searches were undertaken to determine the spawning sites. Methods employed included; visual searching, involving picking up instream rocks and other material and examining them for eggs; drift sampling, setting drift nets for 24 h periods; and kick sampling, taking drift samples downstream of areas when the substrate was being gently disturbed.

Photoperiod during the sampling period was determined from the records made at the Melbourne Planetarium.

The characteristics of each site were measured by measuring depth and recording substrate type at 0.25 m intervals on transects at 5 m intervals along the stream. The characteristics of *G. fuscus* habitat were compared to overall stream characteristics using analysis of variance.

RESULTS

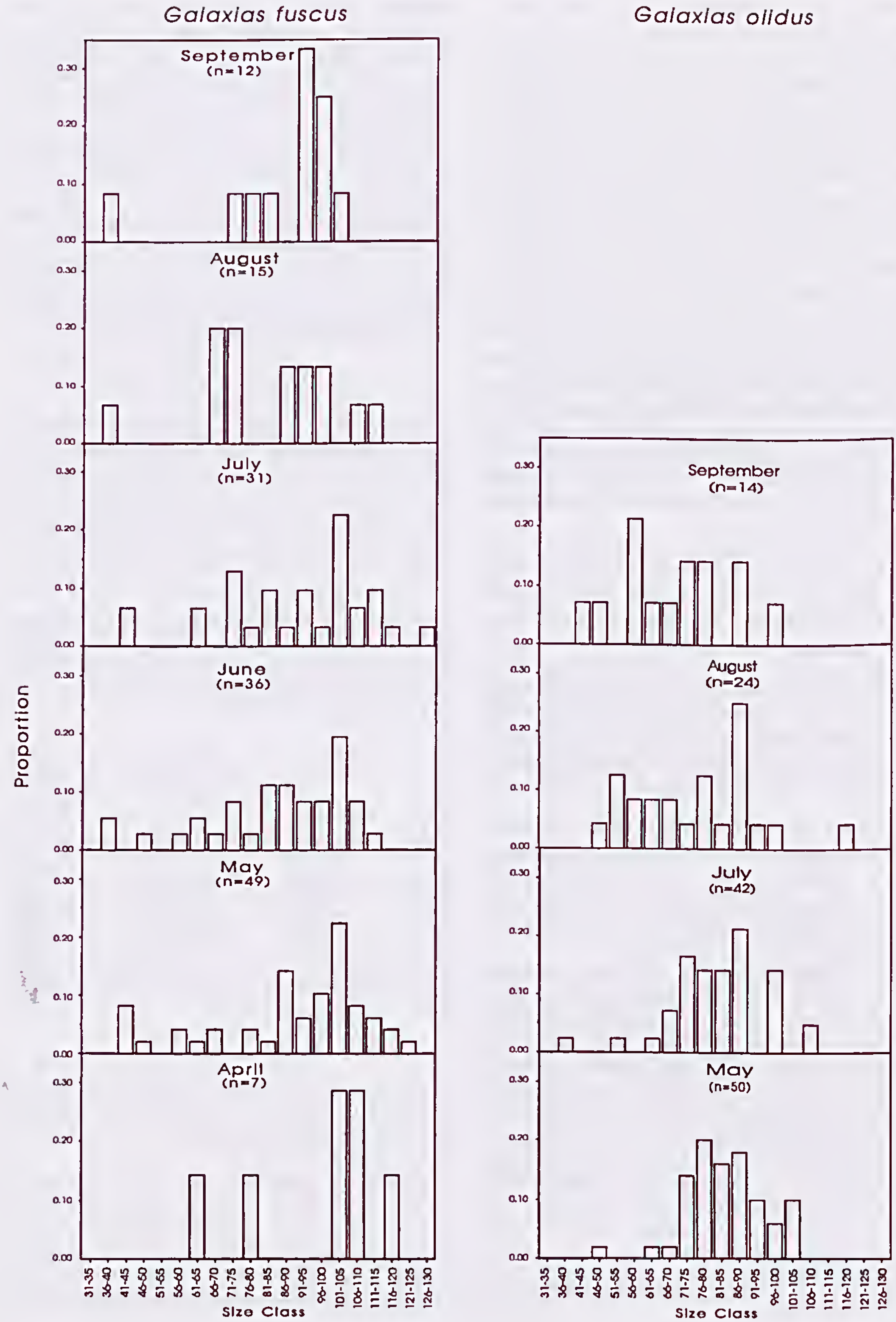
A total of 85 different individuals of *G. fuscus* were collected from the Taggerty River at the 4 sites during the study, whereas a total of 40 different individuals were collected from the two Keppel Hut Creek sites. Therefore, the total number of individuals collected from each stream is a minimum estimate of population size. Estimated population densities of *G. fuscus* ranged between 0.001 and 0.053 fish m^{-2} in the Taggerty River and from 0.010 to 0.036 fish m^{-2} in Keppel Hut Creek (Table 1). In comparison the densities of *G. olidus* in Little River ranged between 0.051 and 0.196 fish m^{-2} (Table 1).

Site	Species	Mean density±SE (fish m^{-2})	Range (fish m^{-2})
KHC3	*G. fuscus*	0.022±0.006	0.010–0.036
TAG1	*G. fuscus*	0.017±0.004	0.014–0.053
TAG2	*G. fuscus*	0.009±0.002	0.004–0.018
TAG3	*G. fuscus*	0.002±0.001	0.001–0.004
TAG4	*G. fuscus*	0.003±0.003	0.003–0.013
LR1	*G. olidus*	0.081±0.003	0.051–0.196

Table 1. Density of *G. fuscus* and *G. olidus* at sampling sites.

The observed sex ratio of females to males in the entire *G. fuscus* population sample (1.00:1.08) was not significantly different from 1:1 (χ^2=0.12, df=1, p>0.50).

It was not possible to determine size classes from our data because of the lack of clear cohorts and our inability to age the samples. Consequently *G. fuscus* and *G. olidus* data was fitted to size classes adapted from O'Connor & Koehn (1991) to allow comparison of population structure


Galaxias fuscus
Galaxias olidus
September (n=12)
August (n=15)
July (n=31)
June (n=36)
May (n=49)
April (n=7)
September (n=14)
August (n=24)
July (n=42)
May (n=50)
Proportion
0.00
0.10
0.20
0.30
31-35
36-40
41-45
46-50
51-55
56-60
61-65
66-70
71-75
76-80
81-85
86-90
91-95
96-100
101-105
106-110
111-115
116-120
121-125
126-130
Size Class

Length range (mm)	*G. fuscus* Number	*G. fuscus* Percentage	*G. olidus* Number	*G. olidus* Percentage
36–52	9	7.31	1	2.00
53–72	15	12.20	3	6.00
73–82	16	13.01	21	42.00
83–100	39	31.71	20	40.00
101+	44	35.77	5	10.00
Total	123		50	

Table 2. Length range and distribution of fish within size classes for *G. fuscus* and *G. olidus*.

(Table 2). A larger percentage of *G. fuscus* individuals were present in the larger size classes than *G. olidus* individuals (Table 2). The mean size of *G. fuscus* adults (95.4 mm) was significantly larger than that of *G. olidus* adults (84.6 mm) (ANOVA, $F=23.377$, $df=1$, $p<0.001$), with the mode of the *G. fuscus* population also being larger. The largest *G. fuscus* caught was 127 mm whereas 115 mm was the largest *G. olidus* caught at the Little River site.

Because of the low sample sizes it is difficult to differentiate cohorts from the size frequency graphs (Fig. 2). The size frequency distributions of *G. fuscus* are even with a tendency towards larger individuals (Fig. 2). The mode of the *G. olidus* size frequency is noticeably smaller than that of *G. fuscus* for most months excluding August (Fig. 2).

G. fuscus in the Taggerty River system during 1991 had an early spring spawning period extending over six weeks (Fig. 3), beginning in late August, and all fish were spent by early October. In comparison the Little River population of *G. olidus* had a four week spawning period starting a few weeks earlier than *G. fuscus*, in early August, and being completed by early September (Fig. 3).

G. fuscus appears to begin running ripe earlier than does *G. olidus* (Fig. 3). By the middle of May 90% of the *G. fuscus* population is in a ripe stage, whereas *G. olidus* are not running ripe until late June. *G. fuscus* starts to develop reproductively quite early, then appears to wait through most of winter before spawning (Fig. 3).

Spawning in *G. fuscus* and *G. olidus* occurred on the increasing photoperiod, with the change in seasons from winter to spring (Fig. 3). There did not appear to be any relationship between water temperature, conductivity or the onset of the snow melt with the spawning of *G. fuscus* or *G. olidus*. Water temperature during the spawning period varied between 4.5°C to 7°C (Fig. 3) showing no distinct trend, and the conductivity remaining very stable between 0–9 µs cm^{-1} for the length of the study. The major snow melt did not begin until early October, well after spawning of both species was complete.

Examination of the fecundity of *G. fuscus* revealed a mean egg number of 512 eggs (range 249–1002) the individuals examined had a mean length of 106 mm (range 83–142). Comparison of the fecundity of *G. olidus* (data from O'Connor & Koehn 1991) and *G. fuscus* (Fig. 4) revealed little differences in the fecundity of the two species. As with *G. olidus* (O'Connor & Koehn 1991) the number of eggs of *G. fuscus* is positively correlated with fish length ($r^2=0.748$, $p<0.001$).

A range of areas within the stream were sampled, both visually and with drift nets, for *G. fuscus* eggs, including spawning substrates known to be utilised by *G. olidus*, but no eggs of *G. fuscus* were found.

Limited spatial data, indicated a preference by *G. fuscus* for slow flowing areas of the stream with water velocity of between 0 and 0.20 m/s, compared to a mean stream velocity of 1.15 m/s. The microhabitat areas utilised were not isolated from the main stream but were usually immediately adjacent to faster flowing water (0.55 to 2.01 m/s). *G. fuscus* also showed a preference for the deeper areas of the stream, with the mean depth of microhabitat being 434 mm compared to a mean overall stream depth of 235 mm. The areas of *G. fuscus* habitat were significantly deeper than the mean stream depth (ANOVA, $F=212.947$, $df=1$, $p<0.001$). Substrate did not appear to be important in the choice of microhabitat as *G. fuscus* were found on all substrate types in similar proportions to the habitat availability.

DISCUSSION

G. fuscus were found to have a late winter early spring spawning period during 1991 extending from August until September. The population of *G. olidus* studied was also found to spawn during the late winter–early spring period,

Fig. 2. Length–frequency graphs for *Galaxias fuscus* in the Keppel Hut Creek and the Taggerty River and *Galaxias olidus* in Little River.

although spawning began two to three weeks earlier than for *G. fuscus*. O'Connor & Koehn (1991) reported *G. olidus* spawning at a similar time of year in Bruces Creek Victoria, although it extended into October, and populations of *G. olidus* in the ACT have been found to spawn

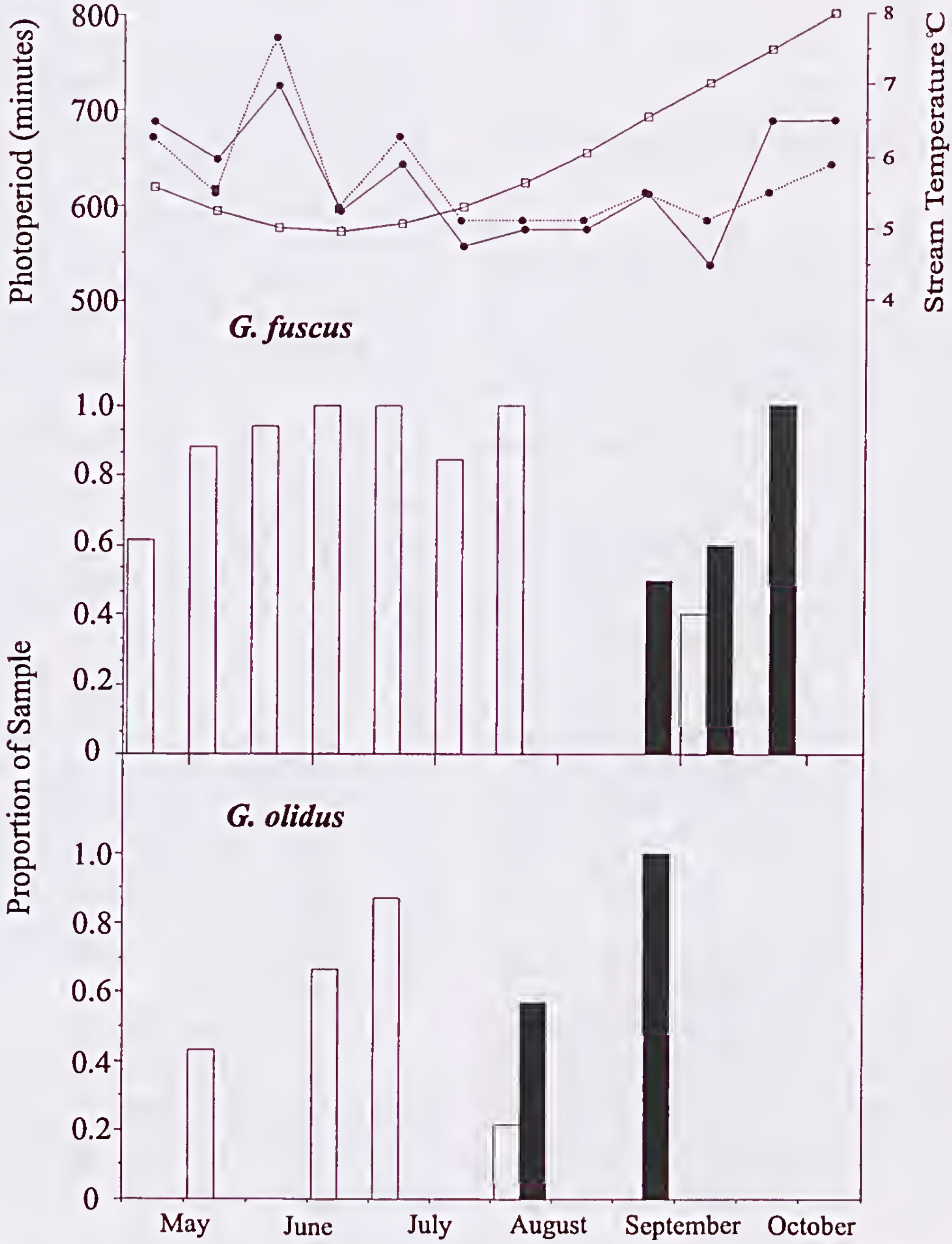


Fig. 3. The relative proportions of ripe (□) and spent (■) *Galaxias fuscus* and *Galaxias olidus* collected during 1991. With photoperiod (–⊟–) and water temperature for the Taggerty River (–●–) and the Little River (....●....) for the same period.

over a similar period but beginning as early as July (Cowden 1988). There appears to be variability in the time of spawning between different populations of *G. olidus* across the geographic range of the species. There is a slight difference in the timing of spawning of *G. fuscus* and *G. olidus* but it is difficult to attribute this to differences between the taxa, because of the intraspecies variation in spawning time through the *G. olidus* complex.

G. fuscus spawned on the increasing photoperiod, with the increasing daylength possibly being the cue to initiate spawning. Changes in the duration of photoperiod have been linked to spawning in other species of endemic fish such as *Galaxias truttaceus* (Humphries 1989) and the gudgeon *Mogurnda adspersa* (Hansen 1988). Temperature has also been suggested as a cue for spawning (Backhouse & Vanner 1978; Tunbridge 1988; Humphries 1989). There were variations in water temperature in the habitat of *G. fuscus* and no clear temperature trend was apparent around the time of spawning. Hence it is not possible to say whether an increase or decrease in water temperature influenced the time of spawning. We suggest that it is the change from decreasing to increasing daylength which triggers spawning in *G. fuscus*, which then occurs on the increasing photoperiod. The *G. olidus* population in Little River also spawned on the increasing photoperiod, with no noticeable trend in water temperature.

There did not appear to be a significant difference in the fecundity of *G. olidus* and *G. fuscus*. *G. fuscus* were the larger individuals with more eggs but, as the closeness of the regression lines reveal, the ratio of fecundity to length seemed to be similar for the two species.

Our study found that *G. fuscus* had a distinct

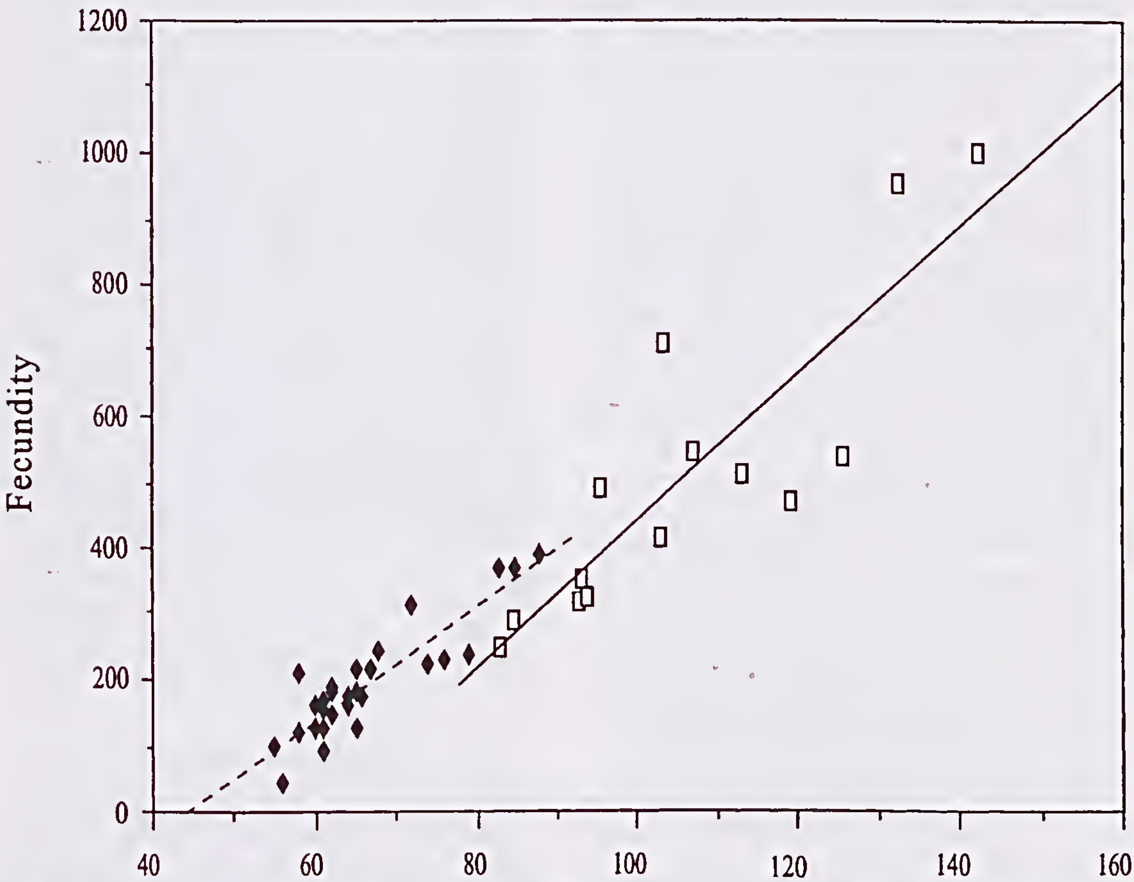


Fig. 4. Relationship between fecundity and length (L.C.F.) for *Galaxias fuscus* (□) with data for *Galaxias olidus* (◆) overlaid from O'Connor & Koehn (1991).

preference for the deeper slow flowing areas of the streams, that is for the pools rather than riffles or cascades. O'Connor & Koehn (1991) found that *G. olidus* were also found predominantly in pools. *G. olidus* inhabits riffles (O'Connor & Koehn 1991), whereas no *G. fuscus* were found in riffles in this study. The lack of *G. fuscus* in riffles may be because they are in lower densities and consequently are not forced into the less favoured riffle habitat, whereas *G. olidus* are forced into the riffle habitats because of their relatively higher instream densities.

G. fuscus is on average a larger fish than *G. olidus*, with more fish in larger size classes and a larger maximum size than *G. olidus* (Table 2). This indicates that *G. fuscus* has either a higher growth rate or a greater longevity in comparison to *G. olidus*. It is difficult to clarify the growth rates of *G. olidus* or *G. fuscus* due to the inconclusive nature of previous work using otoliths for ageing (Cowden 1988; Drayson 1989) and the lack of clear cohorts in our size frequency distributions. Because of the increased length of reproductive investment by *G. fuscus* and the energetic input involved, it is suggested that *G. fuscus*' greater size is attained through greater longevity rather than higher growth rates than *G. olidus*. Thus *G. fuscus* would grow at a similar rate as *G. olidus*, but live for a longer period.

Application of the size classes from O'Connor & Koehn (1991) to the *G. fuscus* population shows that there is a greater proportion of larger *G. fuscus* than there is *G. olidus*. The *G. fuscus* population supports a high proportion of large fish, whereas O'Connor & Koehn (1991) found relatively few *G. olidus* in the 3+ size class. Populations of *G. fuscus* appear to be able to sustain a greater proportion of larger fish than populations of *G. olidus*.

The lower instream density of *G. fuscus* relative to *G. olidus* may mean that *G. fuscus* is under comparatively less pressure for food and habitat space than *G. olidus*. Consequently the lower pressure upon *G. fuscus* may allow the taxon to live longer and attain the greater size recorded. The low instream density of *G. fuscus* may be as a result of high juvenile mortality or aggressive and territorial behaviour contributing to lower population densities of *G. fuscus*.

Because of sampling inefficiencies due to the equipment used, the extremely low conductivities and the constraints placed on sampling, because of the endangered status of *G. fuscus*, it is difficult to extrapolate much about the densities of *G. fuscus*. It is possible to compare the density of the *G. fuscus* populations in the Taggerty River and Keppel Hut Creek with the *G. olidus* densities in Little River because of a continuity of sampling techniques. The instream population densities of *G. fuscus* were significantly less than the densities of *G. olidus* found in Little River by this study (0.051–0.196 fish m^{-2}) or by other previous authors such as O'Connor & Koehn (1991) (1.31–1.70 fish m^{-2}), Tilzey (1976) (2.25–3.70 fish m^{-2}) and Jones et al. (1991) (14.90 fish m^{-1}).

The sex ratio of sexually mature *G. fuscus* did not differ significantly from 1:1, this is in agreement with both O'Connor & Koehn (1991) and Cowden (1988) who both found an overall sex ratio of 1:1. In our study it was not possible to accurately determine whether there was a change in the sex ratio over time particularly in the lead up to spawning, because of the limited size of our samples, as has been suggested for *G. olidus* by several authors (Cowden 1988; Drayson 1989; O'Connor & Koehn 1991).

Further work is required to fully understand the ecology of *G. fuscus* and its relationship within the *G. olidus* complex. Examination of the spawning period over several seasons at more sites is necessary and will increase the chance of finding the sites of egg deposition. An accurate determination of the age cohorts and growth rate of *G. fuscus* and also *G. olidus* is also required.

This initial study has shown that there are some ecological differences between *G. fuscus* and *G. olidus*. The two taxa have a slightly different spawning period, although the site of egg deposition remains unknown for *G. fuscus*. *G. fuscus* is on average a larger fish, which spends more time developing reproductive material. *G. fuscus* populations studied also exist in lower instream densities than known *G. olidus* population densities and *G. fuscus* is very specific in its microhabitat requirements. *G. olidus* prefers pools but is also found in riffles whereas *G. fuscus* was found solely in slow flowing deeper areas of stream (pools). The indications are that further work will show that the ecology of *G. fuscus* and *G. olidus* are further polarised. The differences found in this study lend support to the resurrection of distinct species status for *G. fuscus*.

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